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EXPERIMENTAL INVESTIGATION OF DRYING KINETICS OF PRETREATED AND NON-PRETREATED FIGS (*Ficus carica* L.)

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Abstract

In this study, drying kinetics of non-pretreated and pretreated Sarılop variety figs (Ficus carica L.) were investigated. In experiments, figs were dried whole (unsliced and unpeeled) at 75°C. Experimental moisture ratio curve was compared with Lewis, Page, Modified Page, Henderson and Pabis, Logarithmic, Weibull distribution, Wang and Singh, Two-term, Two-term exponential and Verma et al drying models. Drying of non-pretreatment figs took 50h and model that best fit to the data of experimental moisture ratio was Verma et al model. Drying of pretreatment figs in the sucrose solution at 50°Brix concentration ratio and 50°C temperature under vacuum with osmotic dehydration (130mbar (15min) + atmospheric pressure (165min)) took 28h and it was found that the model best fit to the data of experimental moisture ratio was Weibull distribution model. Drying of pretreatment figs in the sucrose solution at 30°Brix concentration ratio and 50°C temperature under vacuum with osmotic dehydration (130mbar (15min) + atmospheric pressure (165min)) took 38h and it was determined that the model best fit to the data of experimental moisture ratio is Weibull distribution model. Drying of pretreatment figs in the sucrose solution at 50°Brix concentration ratio and 30°C temperature under vacuum with osmotic dehydration (130mbar (15min) + atmospheric pressure (165min)) took 34h and it was seen that the model best fit to the data of experimental moisture ratio was Weibull distribution model. Drying of pretreatment figs in the sucrose solution at 50°Brix concentration ratio and 50°C temperature under atmospheric pressure with osmotic dehydration (180 min) took 46h and it was found that the model best fit to the data of experimental moisture ratio was Wang and Singh model. Results show that osmotic dehydration shortened the drying period. Furthermore, variables in the osmotic dehydration such as concentration ratio of solution, solution temperature and vacuum affected the drying period.

Keywords: Drying, fig, vacuum, osmotic dehydration, moisture ratio, modeling.

ÖNİŞLEM UYGULANMIŞ VE UYGULANMAMIŞ İNCİRLERİN (*Ficus carica* L.) KURUTMA KİNETİĞİNİN DENEYSEL İNCELENMESİ

Özet

Bu çalışmada, önişlem uygulanmamış ile önişlem uygulanmış Sarılop türü incirlerin (Ficus carica L.) kurutma kinetiği incelenmiştir. Deneylerde, incirler bütün (dilimlenmemiş ve kabuğu soyulmamış) olarak 75°C'de kurutulmuştur. Deneysel nem oranı eğrisi Lewis, Page, Modifiye edilmiş Page, Henderson ve Pabis, Logaritmik, Weibull dağılımı, Wang ve Singh, İki terimli, İki terimli eksponansiyel ve Verma vd kurutma modelleri ile karşılaştırılmıştır. Önişlem uygulanmayan incirlerin kurutulması 50h sürmüş ve deneysel nem oranı verilerine en uygun olanın Verma vd modeli olduğu tespit edilmiştir. 50°Brix konsantrasyon oranındaki ve 50°C sıcaklığındaki sakaroz çözeltisinde vakum altında ozmotik dehidrasyon (130mbar (15dk) + açık hava basıncı (165dk)) önişlemi uygulanmış incirlerin kurutma işlemi 28h sürmüş ve deneysel nem oranı verilerine en çok uyan modelin Weibull dağılımı modeli olduğu bulunmuştur. 30°Brix çözelti oranındaki ve 50°C'deki sakaroz çözeltisinde vakum altında ozmotik dehidrasyon (130mbar (15dk) + açık hava basıncı (165dk)) önişlemi uygulanmış incirlerin kurutma işleminin 38h sürdüğü ve deneysel nem oranı verilerine en çok uyan modelin Weibull dağılımı modeli olduğu tespit edilmiştir. 50°Brix çözelti oranındaki ve 30°C'deki sakaroz çözeltisinde vakum altında ozmotik dehidrasyon (130mbar (15dk) + açık hava basıncı (165dk)) önişlemi uygulanmış incirlerin kurutma işlemi 34h sürmüştür ve deneysel nem oranı verilerine en çok uyanın Weibull dağılımı modeli olduğu görülmüştür. 50°Brix çözelti oranındaki ve 50°C'deki sakaroz çözeltisinde açık hava basıncında ozmotik dehidrasyon önişlemi (180dk) uygulanmış incirlerin kurutma işleminin 46h sürdüğü ve deneysel nem oranı verilerine en çok uyanın Wang ve Singh modeli olduğu bulunmuştur. Sonuçlar, ozmotik dehidrasyonun kurutma süresini kısalttığını göstermiştir. Ayrıca, ozmotik dehidrasyonda çözelti konsantrasyon oranı, çözelti sıcaklığı ve vakum değişkenlerinin kurutma süresini etkilediğini göstermiştir.

Anahtar Kelimeler: Kurutma, incir, vakum, ozmotik dehidrasyon, nem oranı, modelleme.

1 Introduction

According to the data of the 2007-2014, annual average value provided by the United Nations Food and Agriculture Organization (FAO), Turkey is in the first place with about 250 thousand tons of production value by providing 27% of the world fresh fig production in the World. Moreover, Turkey

ranks the first with the share of 53% of the World's dried figs production that amounted about 105 thousand tons in 2012/2013. The most preferred type of dried figs produced in Turkey is the Sarılop fig (about 90%) [1].

Figs are widely consumed fresh but have a short harvest time. Drying process is applied to prolong the storability of the figs. Drying, significantly decreases the water activity of the material, reduces microbiological activity and minimizes the physical and chemical changes during storage period of the product [2].

Traditional methods, such as sun-drying or hot-air convective, may cause low nutritive value, low rehydration rate, severe browning and tough texture in dried products. Therefore, there are many different methods applied before the drying step to improve the quality of the dried fruits and vegetables. One of these methods is osmotic dehydration [3].

Osmotic dehydration method is based on the principle of removing water from the plant tissue deeply in a hypertonic solution [4]. Osmotic dehydration preserves attributes of the product such as color, texture and aroma and extends the shelf life of products by reducing the water activity [5]. In recent years, osmotic dehydration of fruits, regarded as a potential method or a complementary way with other conventional dehydration methods or pre-treatment to conventional drying [6].

When the osmotic dehydration used with the application of vacuum, food to be dried put into the solution and is kept a short time under vacuum, and then drying process is continued at atmospheric pressure. Consequently, it is provided to accelerate the transfer of the osmotic fluid from the pores to the product by hydrodynamic mechanism [7].

The most important aspect of drying technology is the mathematical modeling of the drying process and equipment. The purpose of the modeling is to determine the optimum operating conditions to meet the required operating conditions [8]. Recently, studies are conducted on mathematical modeling of the drying behavior of figs [9-12]. But, studies on drying models of pretreated figs are limited.

In this study, it is aimed to investigate drying behavior of figs to which applied osmotic dehydration under vacuum and to compare the results with drying models in the literature. Furthermore, effects of variables in the osmotic dehydration such as concentration ratio of solution, solution temperature and vacuum on drying period are investigated.

2 Material and Method

Sarılop variety figs used in the experiments were harvested from Germencik region of Aydın, Turkey in early September 2014. Fresh figs were about 62g weight. Initial moisture content of figs calculated oven at 70 °C and kept 24h [13] and it was found that initial moisture content was about 74% (wet basis). Figs were used in all experiments as a whole (unsliced and unpeeled). Osmotic dehydration pretreatments were performed at two different temperatures (30°C and 50°C) and two different concentration ratios (30° Brix and 50° Brix) sucrose solutions with a solution/fruit mass ratio of 4/1. The concentration ratio of the solution was measured with digital refractometer (Atago PAL-3, ± 0.1 °Brix) and the solution temperature was measured with multi-thermometer (Testo, Lenzkirch, Germany, ± 0.01 °C).

The system that vacuum was applied consists basically vacuum pump (Edward, RV8, New Jersey, USA), vacuum chamber (Memmert VO-200, Schwabach, Germany) and heat exchanger (Polyscience 9506, Niles, Illinois, USA) (Figure 1). Vapor

evacuated from the vacuum chamber was condensed in the heat exchanger via coolant. The temperature of the vacuum chamber was measured by Testo 434-5 radiofrequency measurement probe.
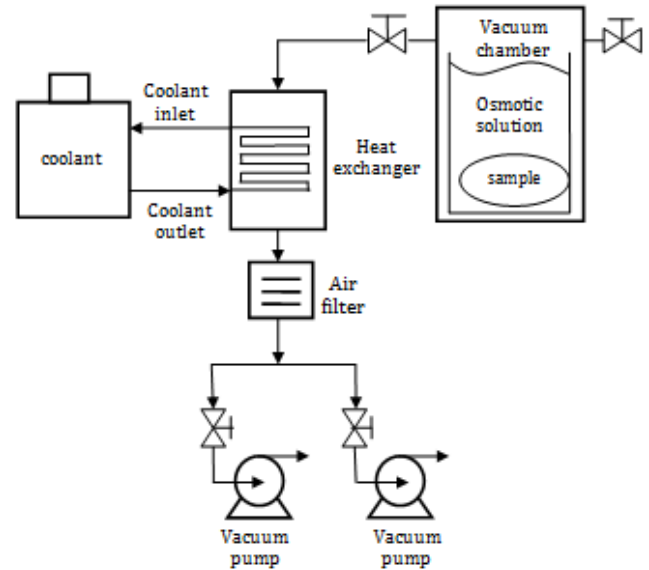

Figure 1. Schematic diagram of the vacuum system.

The system achieved thermal equilibrium in which the temperature of the vacuum chamber and osmotic solution temperature (both 30°C and 50°C) were equal. Figs were placed into the vacuum chamber after completely immersed into the osmotic solution and then vacuum was applied at 130 mbar for 15 min. After the vacuum impregnation, the samples were removed from the vacuum chamber to atmospheric pressure for 165 min, therefore the total pretreatment period lasted for 180 minutes (15 min vacuum + 165 min atmospheric pressure). After the end of the pretreatment, the figs were washed with distilled water for 1 min and gently blotted with absorbent paper and then they were placed into the trays and dried in a convective oven (Ecocell 111, MMM Medcenter) that having heating plate and with no air velocity. The drying process was carried out at 75°C. During the drying process, the weight of the dried figs was measured with precision balance (Precise XT1220M, ± 1 mg). The drying process lasted until the final water content of the product was about 22-23% (based on wet basis) [10].

Table 1. Mathematical models used for the moisture ratio of the figs.

Model no	Model name	Model equation	References
1	Lewis	$MR = \exp(-kt)$	[2, 15, 16]
2	Page	$MR = \exp(-kt^n)$	[2, 15, 16]
3	Modified Page	$MR = a\exp[-(kt^n)]$	[15]
4	Henderson and Pabis	$MR = a\exp(-kt)$	[2, 15, 16]
5	Logarithmic	$MR = a\exp(-kt) + c$	[2, 15, 16]
6	Two-term	$MR = a\exp(-k_o t) + b\exp(-k_1 t)$	[16]
7	Two-term exponential	$MR = a\exp(-kt) + (1-a)\exp(-kat)$	[15]
8	Wang and Singh	$MR = 1 + at + bt^2$	[2, 15, 16]
9	Verma et al.	$MR = a\exp(-kt) + (1-a)\exp(-gt)$	[16]
10	Weibull distribution	$MR = a - b\exp[-(kt^n)]$	[15]

2.1 Drying Kinetics

Moisture ratio (MR) of samples is calculated with Equation (1) [14].

$$MR = (M - M_e)/(M_o - M_e) \qquad (1)$$

where MR is moisture ratio, M is moisture content of sample at any t time (kg water / kg dry matter), M_o is the initial moisture content of sample (kg water / kg dry matter), M_e is equilibrium moisture content (kg water / kg dry matter). The equilibrium moisture content was calculated using the GAB (Guggenheim-Anderson De Boer) relation which was used for figs in literature [11]

2.2 Data Analysis

Equations of the mathematical models used for the moisture ratio of the figs in the literature are given in Table 1. The non-linear regression analysis of equations are given in Table 1 was performed using SPSS 20.0 statistical software and drying parameters and coefficients $(k, k_o, k_1, a, b, c, g, n)$ of these equations were calculated.

Selecting of the best mathematical model was based on the highest R^2 and the lowest $RMSE$ and χ^2 values [17].

The regression coefficient (R^2) was the primary criterion for selecting the most suitable equation established for the determination of the drying curve and it was calculated with Equation (2) [18].

$$R^2 = \frac{\sum_{i=1}^{N}\left(\left(MR_{exp,i} - \overline{MR_{exp,i}}\right)^2 - \left(MR_{pre,i} - MR_{exp,i}\right)^2\right)}{\sum_{i=1}^{N}\left(MR_{exp,i} - \overline{MR_{exp,i}}\right)^2} \quad (2)$$

where N is the total number of observations, $MR_{exp,i}$ is the experimental moisture ratio found in any measurement, $\overline{MR_{exp,i}}$ is the mean of experimental moisture ratio found in any measurement and $MR_{pre,i}$ is the predicted moisture ratio for this measurement.

The root mean square error ($RMSE$) was used to test the short-term performance of the model and was expressed as Equation (3) [19].

$$RMSE = \sqrt{\frac{\left[\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2\right]}{N}} \qquad (3)$$

Chi-square (χ^2), is the mean square of the deviations between the predicted and experimental data and it is calculated with Equation (4) [19].

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N - z} \qquad (4)$$

where z is called number of constants.

3 Results and Discussion

The changes in the moisture ratio of fig samples with drying time are shown in Figure 2. While drying time took 50h for non-pretreated figs, it ranges from 28-46h for pretreated figs depending on the type of pretreatment. When the effect of concentration ratio of solution on the drying time in the osmotic dehydration is analyzed, it is found that drying of pretreated figs at 50°C solution temperature under vacuum with sucrose solution (130mbar (15min)+atmospheric pressure (165min)) took 28h at 50°Brix concentration ratio, and 38h at 30°Brix concentration ratio. When the effect of temperature of solution in osmotic dehydration on the drying time is analyzed, it is found that drying of pretreated figs at 50°Brix concentration ratio under vacuum with sucrose solution (130mbar (15min)+atmospheric pressure (165min)) took 28h at 50°C solution temperature, and 34h at 30°C solution temperature. When the effect of the vacuum on the drying time in the osmotic dehydration is analyzed, it is found that drying of pretreated figs at 50°Brix concentration ratio and 50°C solution temperature took 28h under vacuum with sucrose solution (130mbar (15min)+atmospheric pressure (165min)) and 46h under atmospheric pressure with sucrose solution (180min). Based on these results, we conclude that osmotic dehydration shortens the drying period. Furthermore, variables in the osmotic dehydration such as concentration ratio of solution, solution temperature and vacuum affect the drying period. The results obtained with these experiments are consistent with the results of the study made by An et al. (2013) investing cherry tomatoes.

In this study, the mathematical models that fit best the experimental data have been identified for pretreated and non-pretreated figs drying experiments at 75°C. Using these models, non-linear regression analysis applied to these mathematical models which produced coefficient and statistical values are given in Table 2, Table 3, Table 4, Table 5 and Table 6.

It is found that the model fit best to the data of experimental moisture ratio is *Weibull distribution model* in drying of pretreated figs in the sucrose solution at 50°Brix concentration ratio and 50°C solution temperature under vacuum with osmotic dehydration (130mbar (15min) + atmospheric pressure (165min)) and the results of the statistical and coefficient values are shown in Table 2.
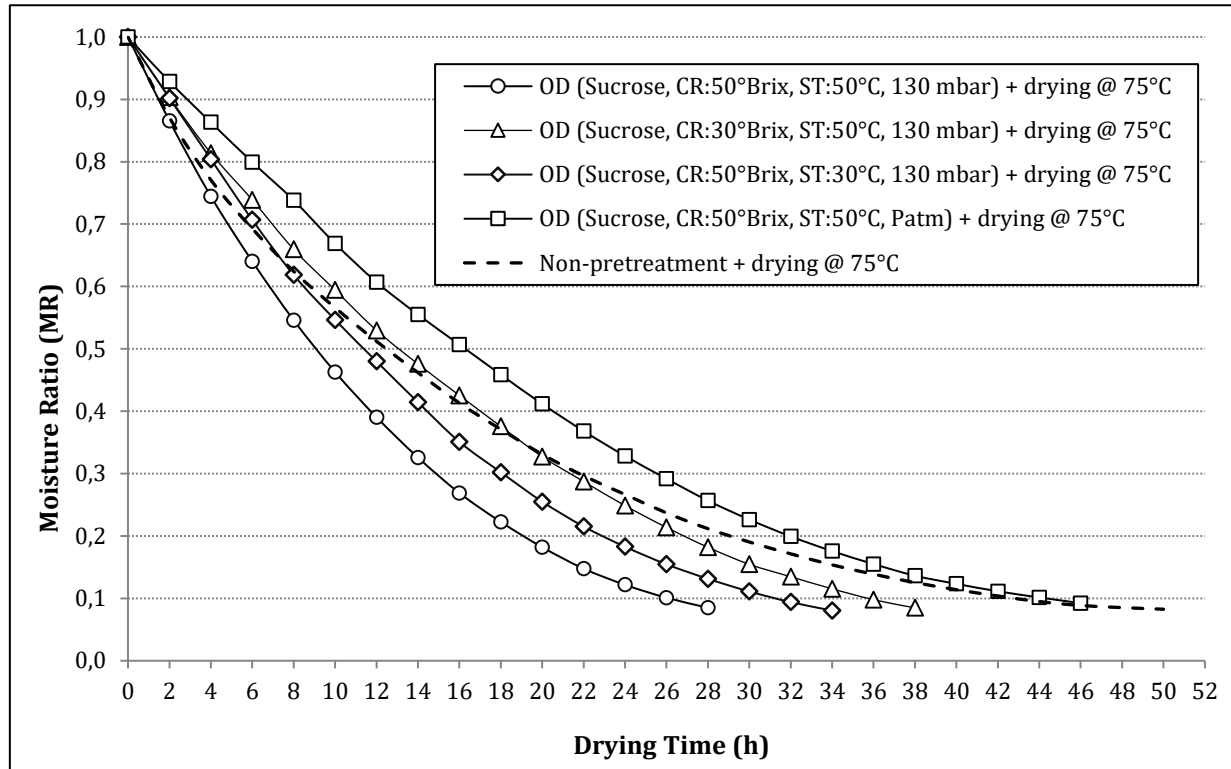
Figure 2. Moisture ratio-time curves of pretreated and non-pretreated figs at 75°C (OD: osmotic dehydration, CR: concentration ratio of solution, ST: temperature of solution).

Table 2. The results of the statistical and coefficient values in drying of pretreated figs at 75°C in the sucrose solution at 50°Brix concentration ratio and 50°C solution temperature under vacuum with osmotic dehydration.

Model No	Coefficients	$RMSE$	R^2	χ^2
1	$k = 0,0813$	0,0177	0,9956	3,37E-04
2	$n = 1,1100; k = 0,0612$	0,0054	0,9996	3,36E-05
3	$a = 0,9926; n = 1,1226; k = 0,0587$	0,0050	0,9997	3,09E-05
4	$a = 1,0252; k = 0,0835$	0,0152	0,9968	2,65E-04
5	$a = 1,0892; c = -0,0825; k = 0,0700$	0,0054	0,9996	3,63E-05
6	$a = 0,5227; b = 0,5025; k_o = 0,0835; k_1 = 0,0835$	0,0152	0,9968	3,14E-04
7	$a = 1,6040; k = 0,1031$	0,0039	0,9998	1,79E-05
8	$a = -0,0649; b = 1,17E - 03$	0,0092	0,9988	9,80E-05
9	$a = -10,2127; g = 0,1206; k = 0,1259$	0,0034	0,9998	1,40E-05
10	$\boldsymbol{a = -0,0362; b = -1,0334; n = 0,0628; k = 1,0699}$	**0,0033**	**0,9998**	**1,49E-05**

It is found that the model fit best to the data of experimental moisture ratio is *Weibull distribution model* in drying of pretreated figs in the sucrose solution at 30°Brix concentration ratio and 50°C solution temperature under vacuum with osmotic dehydration (130mbar (15min) + atmospheric pressure (165min)) and the results of the statistical and coefficient values are shown in Table 3.

It is found that the model fit best to the data of experimental moisture ratio is *Weibull distribution model* in drying of pretreated figs in the sucrose solution at 50°Brix concentration ratio and 30°C solution temperature under vacuum with osmotic dehydration (130mbar (15min) + atmospheric

pressure (165min)) and the results of the statistical and coefficient values are shown in Table 4.

It is found that the model fit best to the data of experimental moisture ratio is *Wang and Singh model* in drying of pretreated figs in the sucrose solution at 50°Brix concentration ratio and 50°C solution temperature under atmospheric pressure with osmotic dehydration (180 min) and the results of the statistical and coefficient values are shown in Table 5.

It is found that the model fit best to the data of experimental moisture ratio is *Verma et al model* in drying of non-pretreated figs and the results of the statistical and coefficient values are shown in Table 6.

Table 3. The results of the statistical and coefficient values in drying of pretreated figs at 75°C in the sucrose solution at 30°Brix concentration ratio and 50°C solution temperature under vacuum with osmotic dehydration.

Model No	Coefficients	$RMSE$	R^2	χ^2
1	$k = 0,0570$	0,0225	0,9929	5,34E-04
2	$n = 1,1336; k = 0,0385$	0,0096	0,9987	1,03E-04
3	$a = 0,9836; n = 1,1648; k = 0,0345$	0,0086	0,9990	8,68E-05
4	$a = 1,0308; k = 0,0589$	0,0196	0,9946	4,28E-04
5	$a = 1,1363; c = -0,1333; k = 0,0452$	0,0048	0,9997	2,67E-05
6	$a = 0,4910; b = 0,5398; k_o = 0,0589; k_1 = 0,0589$	0,0196	0,9946	4,81E-04
7	$a = 1,6425; k = 0,0740$	0,0084	0,9990	7,77E-05
8	$a = -0,0452; b = 5,63E - 04$	0,0082	0,9991	7,39E-05
9	$a = 0,7640; g = 0,0570; k = 0,0570$	0,0225	0,9929	5,97E-04
10	$\mathbf{a = -0,0954; b = -1,0917; n = 1,0435; k = 0,0419}$	**0,0041**	**0,9998**	**2,14E-05**

Table 4. The results of the statistical and coefficient values in drying of pretreated figs at 75°C in the sucrose solution at 50°Brix concentration ratio and 30°C solution temperature under vacuum with osmotic dehydration.

Model No	Coefficients	$RMSE$	R^2	χ^2
1	$k = 0,0664$	0,0245	0,9919	6,38E-04
2	$n = 1,1586; k = 0,0427$	0,0049	0,9997	2,67E-05
3	$a = 0,9935; n = 1,1706; k = 0,0409$	0,0045	0,9997	2,45E-05
4	$a = 1,0408; k = 0,0693$	0,0197	0,9948	4,38E-04
5	$a = 1,1239; c = -0,1074; k = 0,0555$	0,0086	0,9990	8,84E-05
6	$a = 0,6187; b = 0,4222; k_o = 0,0693; k_1 = 0,0693$	0,0197	0,9948	5,00E-04
7	$a = 1,6853; k = 0,0883$	0,0041	0,9998	1,93E-05
8	$a = -0,0526; b = 7,57E - 04$	0,0051	0,9996	2,94E-05
9	$a = 0,7680; g = 0,0664; k = 0,0664$	0,0245	0,9919	7,23E-04
10	$\mathbf{a = -0,0233; b = -1,0205; n = 1,1323; k = 0,0436}$	**0,0037**	**0,9998**	**1,79E-05**

Table 5. The results of the statistical and coefficient values in drying of pretreated figs at 75°C in the sucrose solution at 50°Brix concentration ratio and 50°C solution temperature under atmospheric pressure with osmotic dehydration.

Model No	Coefficients	$RMSE$	R^2	χ^2
1	$k = 0,0467$	0,0292	0,9885	8,88E-04
2	$n = 1,1904; k = 0,0258$	0,0063	0,9995	4,33E-05
3	$a = 0,9880; n = 1,2145; k = 0,0236$	0,0054	0,9996	3,39E-05
4	$a = 1,0502; k = 0,0492$	0,0232	0,9928	5,85E-04
5	$a = 1,1610; c = -0,1411; k = 0,0373$	0,0110	0,9984	1,37E-04
6	$a = 0,4901; b = 0,5601; k_o = 0,0492; k_1 = 0,0492$	0,0232	0,9928	6,43E-04
7	$a = 1,7297; k = 0,0639$	0,0055	0,9996	3,28E-05
8	$\mathbf{a = -0,0370; b = 3,75E - 04}$	**0,0031**	**0,9999**	**1,05E-05**
9	$a = 0,2264; g = 0,0467; k = 0,0467$	0,0292	0,9885	9,72E-04
10	$a = -0,0160; b = -1,0070; n = 1,1867; k = 0,0250$	0,0052	0,9996	3,24E-05

Table 6. The results of the statistical and coefficient values in drying of non-pretreated figs at 75°C.

Model No	Coefficients	$RMSE$	R^2	χ^2
1	$k = 0,0559$	0,0109	0,9981	1,24E-04
2	$n = 0,9459; k = 0,0659$	0,0063	0,9994	4,26E-05
3	$a = 0,9913; n = 0,9575; k = 0,0630$	0,0060	0,9994	4,02E-05
4	$a = 0,9760; k = 0,0545$	0,0077	0,9991	6,41E-05
5	$a = 0,9672; c = 0,0148; k = 0,0568$	0,0067	0,9993	5,14E-05
6	$a = 0,9580; b = 0,0422; k_o = 0,0534; k_1 = 0,8617$	0,0047	0,9996	2,64E-05
7	$a = 0,0399; k = 1,3429$	0,0048	0,9996	2,50E-05
8	$a = -0,0440; b = 5,31E - 04$	0,0331	0,9827	1,18E-03
9	$\mathbf{a = 0,0420; g = 0,0534; k = 0,8602}$	**0,0047**	**0,9996**	**2,52E-05**
10	$a = -0,0050; b = -0,9974; n = 0,9492; k = 0,0640$	0,0059	0,9994	4,15E-05

The comparison of drying models fits the most and the least to the value of experimental moisture ratio is shown in Figure 3 for drying of pretreated figs at 75°C in the sucrose solution at 50°Brix concentration ratio and 50°C solution temperature under vacuum with osmotic dehydration (130mbar (15min) + atmospheric pressure (165min)).
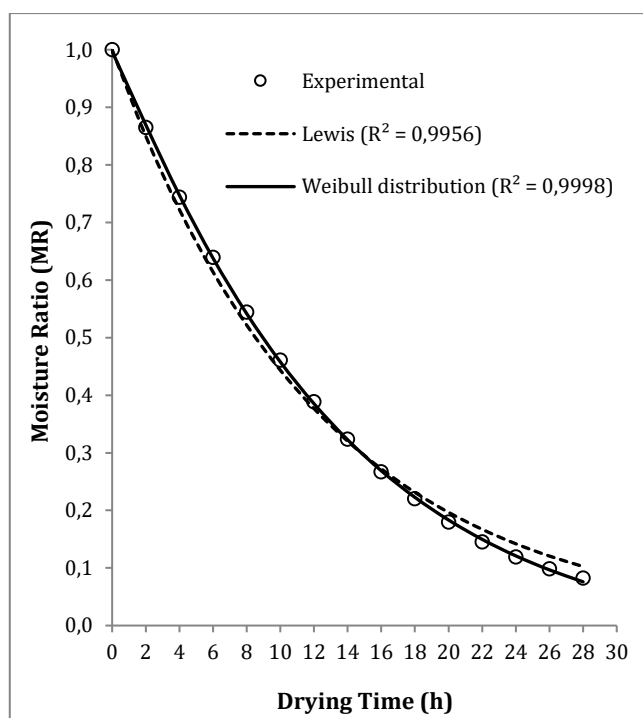
Figure 3. The comparison of drying models fits the most and the least to the value of experimental moisture ratio for drying of pretreated figs at 75°C in the sucrose solution (50°Brix and 50°C) under vacuum.

In this experiment it is shown that the model that fits the best the experimental moisture ratio is *Weibull distribution model* and fits the least the experimental moisture ratio is *Lewis model*.

4   Conclusion

Drying time of non-pretreated figs took 50h and model that fit best to the data of experimental moisture ratio is *Verma et al model*.

Drying of pretreated figs in the sucrose solution at 50°Brix concentration ratio and 50°C solution temperature under vacuum with osmotic dehydration (130mbar (15min) + atmospheric pressure (165min)) took 28h and it is found that the model fit best to the data of experimental moisture ratio is *Weibull distribution model*.

Drying of pretreated figs in the sucrose solution at 30°Brix concentration ratio and 50°C solution temperature under vacuum with osmotic dehydration (130mbar (15min)+ atmospheric pressure (165min)) took 38h and it is determined that the model fit best to the data of experimental moisture ratio is *Weibull distribution model*.

Drying of pretreated figs in the sucrose solution at 50°Brix concentration ratio and 30°C temperature under vacuum with osmotic dehydration (130mbar (15min) + atmospheric pressure (165min)) took 34h and it is seen that the model fit best to the data of experimental moisture ratio is *Weibull distribution model*.

Drying of pretreated figs in the sucrose solution at 50°Brix concentration ratio and 50°C temperature under atmospheric pressure with osmotic dehydration (180 min) took 46h and it is found that the model fit best to the data of experimental moisture ratio is *Wang and Singh model*.

Results show that osmotic dehydration shortened the drying period. Furthermore, variables in the osmotic dehydration such as concentration ratio of solution, solution temperature and vacuum affected the drying period.

5   Acknowledgment

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